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ABSTRACT

The development of a series of parallel single-topic tests for testing attainment of 14 objectives concerned with inquiry skill in biology is discussed. The series of eight two-part tests are called "Explorations in Biology" (EIB). (CK)

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CRITERION-REFERENCED TESTS IN BIOLOGY

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Paper presented at American Educational Research Association Meeting in Chicago, Illinois, April 1972.

Criterion-referenced Tests in Biology*

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Introduction

This report deals with the development of a series of parallel single-topic tests developed by McREL staff members to test attainment of fourteen objectives concerned with inquiry skill in biology. These objectives were identified as being accessible to assessment by means of paper-and-pencil multiple-choice tests. The series of eight two-part tests are called EXPLORATIONS IN BIOLOGY (EIB hereafter). The single-topic, simulation format was selected to accommodate the unitary nature of an inquiry. The data resulting from field trials of the six EIB Topics available in 1971 were made possible through the cooperation of a number of schools and colleges interested in aiding in the development of a measure by which effectiveness of instruction in inquiry processes might be assessed. Over 1500 students in private and public schools have taken these tests during the development process begun three years ago; states involved were Connecticut, Illinois, Hawaii, Louisiana, Missouri, Nebraska and Pennsylvania.

Objectives were selected for the EIB based on studies by Burmester[1], Kaplan[2], Suchman[3] and Taba[4]. With the completion of the detailed McREL-BSCS set of objectives[5], studies were made to learn the extent to which EIB items could be referenced to similar objectives listed in that document (IOTB hereafter).

Items at several difficulty levels could be written to test the objectives to which the EIB is referenced. This particular series is intended for the average student in the first course in high school biology, usually offered in the sophomore year. Some of this target group taking the EIB's as a pre-test in the fall may demonstrate attainment of a particular criterion level or score set by the teacher. There would then be no need for these particular students to take instruction intended to guide the target group toward this level. A need is implied by this contingency, of course, for EIB tests to be written to test objectives at higher levels of complexity.

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1. Burmester, Mary Alice. Behavior involved in the critical aspects of scientific thinking. Science Education, December, 1952, 36, 259-263
2. Kaplan, E. H. The Burmester Test of aspects of scientific thinking as a means of teaching the mechanics of the scientific method. Science Education, October, 1967, 51 (4), 353-357.
3. Suchman, J. R. The Elementary School Training Program in Scientific Inquiry. Project 216, USOE, University of Illinois, June, 1962.
4. Taba, Hilda. Teaching strategy and learning. California Journal of Instructional Improvement. December, 1963.
5. Bingman, R. M., Ed. Inquiry Objectives in the Teaching of Biology. Kansas City: McREL, 1969.

The next major objective, however, is the solution of problems of lack of equivalence of various EIB Topics, then studies of effectiveness of objective-referenced items pooled from several Topics.

Characteristics of Items

Items were written by educators and test construction specialists familiar with 10th-grade biology curricula, and with inquiry processes. The number of response options (two to five) offered for each item differs from section to section. All are uniform in that a decision based on what has been presented in the test to that point is to be made. The vocabulary level is generally ninth to tenth grade[6].

To check appropriateness of these items for the target group, a wide range of students was sampled, including ninth-graders and college freshmen. The overlap in scores between the high school level and the college level led to the inclusion of college freshmen in the target group . It was, however, concluded that the EIB is not appropriate for any ninth-grade group other than those identified as having above-average aptitude or achievement.

Two of the usual methods of item analysis are being applied to Topics administered last spring. First, if two options appeared equally attractive to most students, the item is revised to yield a more clear-cut appeal by the "correct" response option. Secondly, if an item showed negative discrimination, it is revised or eliminated and another substituted.

Items responded to correctly by only a few students at the end of the term are also revised, on the assumption that a sizeable proportion of the total sample had had effective instruction in inquiry processes during the year.

From comparisons of percentages of students selecting "correct" answers in the fall prior to instruction and later on at the end of the term, it will be possible to identify those items most sensitive to effects of instruction; the extent to which such items are indicators of effect of inquiry instruction can be reflected by the scoring weight attached to the desired response on these items.

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6. Dale, E. and Chall, Jeanne S. A formula for predicting readability. In Hunicutt, C. W. and Iverson, W. J. Research in the Three R's. New York: Harper and Brothers, 1958, 194-213.

Characteristics of the Scoring System

Because the scoring of responses is based on the judgment of test writers as to the preferred inquiry process response, and not on answers that are related to memory for facts or understanding of concepts, a weighted scoring system appeared desirable. This resulted in some variability among the total scores possible for the various booklets. Maximum possible scores for the two parts of each Topic (planning and implementation of the investigation) as well as scores that might be attained by chance are shown in Table 1. The latter might prove useful to the teacher in the setting of the criterion score to be attained after instruction.

Table 1

Maximum Score Possible and Chance Score for EIB 1-6

EIB	Maximum Possible Score	Chance Score
1-A	72	35.36
1-B	89	38.80
2-A	75	36.70
2-B	82	35.45
3-A	77	33.84
3-B	78	34.45
4-A	78	35.14
4-B	55	24.20
5-A	66	31.40
5-B	113	51.62
6-A	87	37.70
6-B	54	24.90

Concurrent Validity

a. The relationship between total EIB-1 scores and multiple rating by peers or teachers (studied separately) on the Behavioral Checklist for Science Students[7] was studied based on the rationale that classroom and/or school behaviors indicating high interest and skill in discussion of scientific inquiry should be positively related to EIB total score. This was not the case in the results from application of a Pearson product-moment correlation formula to the scores; a zero-order r resulted. Because the scattergram appeared to suggest a curvilinear relationship, this correlation was computed and found to be somewhat higher (.36 between average peer rating and EIB-1 (N = 150); .30 between rating by teacher and EIB-1). Neither statistic is convincing evidence of concurrent validity for EIB-1.

7. Koos, Eugenia M. and Afsar, Sibel. A Behavioral Checklist for Science Students. Kansas City: McREL, 1968.

b. Three estimates of the relationship between the Processes of Science Test[8] and EIB total score have been low: Pearson r with EIB-1 was .37 (N = 29) and .22 (N = 13); r with EIB-3 was .09 (N = 37). The limited number of cases involved precludes the giving of much weight to this finding, however. Two structural aspects of the POST detract even more directly from its utility as a measure of concurrent validity for an inquiry skill test: one is the inclusion of items related to career knowledge and the other its probable 11th-grade or higher readability level.

Content validity

The original objectives to which EIB items are referenced[9] are as follows:

1. Identifying a phenomenon to investigate.
2. Identifying the question arising from the identification of this phenomenon.
3. From a list of readings, selecting and evaluating reports that might yield useful information about the event noted.
4. Differentiating likely causes of this event from unlikely causes.
5. Selecting a single hypothesis to investigate.
6. Selecting an array of methods appropriate to the investigation.
7. Identifying the independent variable to be studied.
8. Identifying conditions required for conducting a laboratory study on this topic.
9. Choosing a plan which would yield data affording a test of the hypothesis.
10. Identifying assumptions necessary for interpretation of data resulting from carrying out the plan.
11. Identifying the data which would result from carrying out this plan.
12. Identifying justifiable conclusions from data associated with a class experiment on this topic.
13. From a heterogeneous list of questions, identifying new questions which might arise as a result of carrying out this investigation.
14. Integrating results of this study with those reported by other investigators in related areas.

To study the relationship of these items to another set of inquiry skill objectives, persons well-acquainted with inquiry instruction were asked to judge whether EIB items could be referenced to the McREL-BSCS IOTB. With the exception of a section of items assigned by one judge to the affective domain of inquiry, other items were assigned to one or another of the IOTB cognitive skill objective categories. Content validity was thus to be inferred from the judgments that EIB items tested one or another of these objectives.

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8. Biological Sciences Curriculum Study. Processes of Science Test. New York: The Psychological Corporation, 1965.
9. Koos, Eugenia M. Technical Report No. 1. A report on developmental studies of a series of measures of inquiry skill in biology, Explorations In Biology. McREL, Kansas City, Mo., 1970.

Construct Validity

Several measures of cognitive ability underlying inquiry skill were studied as a means of identifying the construct validity of the EIB. The DAT Verbal Reasoning subtest percentile score has been found to correlate .69 (N = 46) with EIB-1 and .42 (N = 116) with EIB-3 (Table 2). For the Watson-Glaser Critical Thinking Appraisal total score, the Pearson r with EIB-1 was found to be .43 (N = 83). These results suggest that the skills assessed by the EIB are rather highly related to verbal reasoning, and to a lesser extent to critical thinking. On the other hand, the probable effect of the very high readability level of the Watson-Glaser is that the correlation is less than would be the case if a form more appropriate for the average high school sophomore were available.

Table 2

Inter-relationships of EIB-1 or EIB-3 Total Scores with Measures of Aptitude or Achievement*

Aptitude or Achievement Test	N	r with EIB-1	N	r with EIB-3
ITBS	45	.57	121	.48
SCAT-V	21	.41	38	.35
SCAT-N	20	-.01	38	.33
DAT-V	46	.69	116	.42
DAT-N	44	.39	114	.36
SHSPT-V	69	.45	33	.57
SHSPT-Q	69	.58	33	.59
SHSPT Reading	69	.42	33	.75
SHSPT Biology	68	.19	32	.51
Watson-Glaser	83	.43		

Aptitude test scores from records of administration during 8th grade

Of note is the correlation of .75 between Scholastic High School Placement Test (SHSPT) Reading subtest score and EIB-3 total score (N = 33). This finding raises a question as to the appropriateness of the ninth-grade reading level for a test for high school sophomores, but also affirms the existence of the generally-recognized common factor of intelligence underlying skill in inquiry, reading, and other areas involving verbal reasoning.

*ITBS. Lindquist, E.F., Hieronymus, A.N., and others. Iowa Tests of Basic Skills, 1955-56. Houghton Mifflin Company, New York.

SCAT. School and College Ability Test. Educational Testing Service, Princeton, New Jersey.

DAT. Bennett, G.K., Seashore, H.G., and Wesman, A.G. Differential Aptitude Tests. New York: The Psychological Corporation, 1959.

SHSPT. Anderhalter, O.P., Gawkoski, R.S. and O'Brien, J. Scholastic High School Placement Test. Scholastic Testing Service, Bensonville, Illinois, 1959.

Watson, G. and Glaser, E.M. Watson-Glaser Critical Thinking Appraisal, Form YM. New York: Harcourt, Brace and World, 1961.

Internal Consistency

A Kuder-Richardson 20 index of internal consistency was found to be .96 for the initial EIB-1 form, for which unweighted scoring was used (N = 451). Another estimate of .74 was obtained with N = 150 in a more homogeneous sample. Because of the inclusion of optional items in the total score, this can be considered only a rough estimate. With the adoption of weighted scoring for EIB tests developed later, a Cronbach alpha was computed for each of Books A and B separately.

Separate estimates of internal consistency were derived by grouping student scores for Book B according to the experimental plan selected for study by the student. The following table shows the findings for the various EIB Books A and B treated separately, with estimates for each Book B derived as described above.

Table 3

Cronbach alpha Indices of Internal Consistency of EIB Topics 1-6

Book A			Book B	
EIB	N	Alpha	N	Alpha
1	705	.80	442	.86
			43	.68
			336	.84
2	381	.84	371	.83
			86	.83
			56	.90
			184	.75
3	1046	.80	891	.83
			323	.83
			167	.78
			60	.81
			149	.87
			169	.75
4	281	.67	266	.74
			191	.68
5	315	.76	264	.75
			96	.76
			32	.79
			82	.79
6	273	.76	252	.81
			104	.82
			86	.83

This index of reliability appears to be the only appropriate procedure for a sequential test such as the EIB. A study made of the test-retest stability of EIB-1, Book A yielded a Pearson r of .66 (N=52) with one week intervening between test administrations. However it was concluded that this was not a satisfactory index due to the probability that the student's second response to the instrument would be altered due to his exposure to readings contained in the test and intervening opportunity for reassessment of decisions made.

Intercorrelation of Various EIB Topics

Although the format and procedures are almost identical in the six EIB Topics studied, interrelationships between tests have been only moderate in most instances. While the relatively small numbers and relative homogeneity of scores involved in these studies (N from 28 to 74) account for this finding to some extent, this finding suggests that the tests should not be used as alternate forms until higher intercorrelations between the tests are obtained. This may be accomplished by collection of data from a more heterogeneous sample on the various EIB tests incorporating the item revisions discussed above.

Table 4 below shows the Pearson r for each pair of EIB Topics administered to students in the high school and college sample.

Table 4

Intercorrelations of EIB 1-6 Total Scores of Various High School and College Classes

EIB Tests	N	Pearson r
1-3	34	.57
2-4	28	.66
2-6	74	.51
3-5	48	.61
4-6	54	.63
5-6	59	.38

To date, the extent of the relationship between sets of two or more EIB Topics has not been studied; this is, however, a major long-range objective.

Intercorrelations of Books A and B

In the absence of valid information on the tested relationship between mastery of the planning inquiry skills included in Book A and the implementation skills in Book B of the EIB format, it was anticipated that there would be low positive correlations between subtotal scores for these parts. As shown in the table below, this was found to be the case, with a higher relationship noted only for EIB-6.

Table 5
Intercorrelations of EIB Books A and B

EIB No.	N	r AB
1	451	.38
1	108	.19
2	107	.23
3	300	.31
4	238	.29
5	243	.26
6	131	.46

As yet unexplored is the degree of intercorrelation between two different EIB Book A's and between two Book B's.

Use of Fall-Spring Comparisons of Class EIB Total and Subtotal Scores to Assess Criterion Attainment by the Group

Science educators as yet have not made any estimate of a minimum criterion level of attainment on the EIB tests, inasmuch as they apparently have the feeling that any attainment would be welcome. The availability of information on fall '71 and spring '72 mean EIB total scores of a range of classes given instruction in inquiry should provide the basis for selection of a numerical minimal EIB criterion level to be attained after a term of instruction. The provision in the statement of the scoring system of the chance score offers teachers a guide to the minimum score that might be expected of the average student.

Data on EIB total score class means pre- and post-instruction (Appendix A) may be useful to teachers in setting criterion levels. Class means are shown in rank order. Included are ninth-grade general science, tenth-grade biology and college biology classes in the various test sites.

A useful method for assessing effectiveness of instruction would be the random assignment of different EIB tests to different students in a given class. This would have the effect of administration of a broader sampling of items to the class as a unit.

As responses from groups of two or more EIB's are available for study, subtests of at least minimal length for valid use and internal consistency will become available. These should provide measures of specific objective skills or closely-related clusters of skills.

Order of Selection of Steps in Book A, EIB-1, -2 and -3

Although student preference as to initial and subsequent steps to take in the EIB tests is not presently scored, science educators have shown considerable interest in this variable. Alternative steps offered to the students in the 1970-71 versions of the EIB were:

A. Read a list of possible explanations of what happened in the pictures. Select two, either of which you would investigate first.
B. Read and rate four out of ten reports about the puzzling event which may give useful information about the events in the pictures.
C. Read a list of questions about the puzzling event. Choose an important one to ask first after seeing these pictures.
D. Read a list of ways to get new data to explain the puzzling event. Pick out the most useful ways.
E. Read a list of possible explanations of the puzzling event in the pictures. Decide whether each is likely or not likely to be worth investigating.

Tables 6, 7 and 8 below show results of studies of preference for a given first step and order of selection of subsequent steps in various student groups responding to EIB-1, -2 and/or -3. It can be seen from data in Tables 6 and 7 that Step E, deciding whether possible explanations are likely to be worth investigating, is the universally most popular first step.

Table 6
Rank of Most Popular Patterns
on EIB -1, -2 and -3

Rank	N	Pattern
1	22	EDABC
2	18	EADBC
3	16	EABCD
4	12	DAEBC
6	11	EBADC
6	11	EDACB
6	11	CBEAD
8	10	CDBEA
10.5	8	EABDC
10.5	8	EADCB
10.5	8	CDEAB
10.5	8	CEADB

Table 7
Rank and Mean EIB Score of Groups
Choosing Given Pattern

EIB	Rank	N	Pattern	Total Score Mean
1	1	8	EADBC	112.1
1	2.5	6	EDACB	113.8
1	2.5	6	EABCD	112.8
2	1	5	EDABC	65.6
2	2	4	EADBC	78.2
3	1	10	EDABC	81.8
3	2.5	7	EABCD	82.0
3	2.5	7	DAEBC	71.1

However, when one compares means of groups selecting each step initially, it is clear that E was not chosen by high-scoring students (Table 8).

Table 8
Means of Groups Choosing Different First
Steps on EIB-1A, 2A or 3A

EIB No.	Letter of Step Chosen First	Mean of Group Choosing Letter	N
1	B	117.4	7
	C	111.9	30
	A	108.4	9
	E	107.2	69
	D	104.4	27
2	A	93.0	5
	B	92.3	3
	C	91.0	8
	E	69.2	17
	D	58.7	3
3	C	92.0	46
	E	76.6	55
	B	72.3	23
	D	70.1	33
	A	64.9	38

A further study was made by chi square analysis of the significance of first step differences between students in upper and lower quartiles on each EIB. From the results shown in Table 9, it can be seen that high-scoring students chose Step C (on EIB-3) while lower-achieving students preferred A or D, with the difference in frequency yielding a chi square of 25.68, with $p < .001$. Step C involves the asking of the appropriate question, while Step A involves the selection of two alternative hypotheses for investigation and D refers to selection of appropriate methods.

Table 9
Results of Chi Square Analysis of First Step Preferences of
EIB-3 Total High or Low-Scoring Groups. Spring, 1970

First Step Chosen	No. Taking Test	Upper 25% Choosing Step	Lower 25% Choosing Step
A	43	8	20
B	23	3	7
C	49	24	3
D	37	4	10
E	64	14	13
	216	53	53

$X^2 = 25.68$
$df = 4$
$p < .001$

Chi square analyses for 1970 data on EIB-1 and -2 responses could not be performed due to small expected cell frequencies.

Role of Entry Tests in Setting of Criterion Levels of Attainment for Biology Classes

The foregoing discussion of the setting of levels for a class at the outset of instruction leads to the oft-stated precept that entry skill tests are obligatory if criterion levels are to be realistic goals for a given group of students. Specifically for the EIB, no student with less than a tested ninth-grade reading ability should attempt to respond without assistance on material he does not understand; even then, it would be difficult to determine if his performance was completely unaffected by low reading ability.

Assumptions about the particular scientific vocabulary known to entering sophomore biology students also might desirably be checked prior to instruction. While a number of terms are defined in each EIB, a vocabulary pre-test for each should be produced for administration a few days prior to each testing session in order to allow the teacher to identify and assist students lacking acquaintance with more widely-known terms.

Without these safeguards and aids to the teacher, use of the EIB series as criterion-referenced tests would be based on only partial information.

Conclusions

From this report of studies of the EIB Topics, it is clear that further work is needed to define the extent to which it will be useful. One potential value of this tool is its use as a means of linking inquiry skills to Guilford's structure of the intellect model through factor analysis.

Perhaps then we will be in a position to respond in some detail to Jackson's[10] contention that the more complex cognitive skills are inaccessible to criterion-referenced testing.

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10. Jackson, Rex. Developing Criterion-referenced Tests, Princeton, N. J., Educational Testing Service, 1972 (TM Report No. 1, ERIC Clearinghouse on Tests, Measurement and Evaluation).

Appendix A

Table 10

Class Means and Standard Deviations of EIB 1-6 Total Scores
of High School (9-10) and College Freshman Students

EIB No.	No. Students	Teacher/ Section	Date/ Subject	Class Mean	S. D.	School/ College
			Spring, 1971			
1	42	261	Gen. Biology	112.90	14.14	Univ. Lab School
1	19	122	Fresh. "	106.47	17.92	State College
1	26	211	" "	104.62	17.16	" "
1	21	221	" "	94.05	19.85	" "
	108	All		104.51		
			Fall, 1970			
2	16	294	Conservation	86.25	13.85	Urban Schools
2	13	277	Biology	76.54	23.71	affiliated with
2	19	291	" "	76.47	16.90	University
2	23	295	" "	65.35	17.38	Science
2	18	283	Research	63.50	17.73	Research
2	18	287	Biology	63.00	17.75	Program
2	21	298	Conservation	55.19	19.44	
2	20	292	Biology	47.70	19.45	
2	148	All		65.68	21.25	
			Spring, 1971			
3	7	53	Gen. Biology	95.71	9.01	Urban High School
3	9	21	" "	91.22	9.80	Private H. S.
3	17	122	Fresh. "	90.65	16.75	College
3	22	56	Gen. "	89.82	13.74	Urban High School
3	8	23	" "	88.25	12.58	Private H. S.
3	7	24	" "	87.86	12.75	" " "
3	6	22	" "	87.83	10.65	" " "
3	21	221	Fresh. "	85.00	16.16	College
3	21	254	Gen. "	83.57	14.75	Consol'd H. S.
3	26	51	" "	82.88	13.78	Urban High School
3	25	253	" "	82.32	13.18	Consol'd H. S.
3	14	255	" "	82.07	19.57	" " "
3	20	57	" "	81.10	12.69	Urban High School
3	19	251	" "	79.10	16.88	Consol'd H. S.
3	23	257	" "	74.91	12.93	" " "
3	23	34	Gen. Science	71.70	11.17	Urban High School
3	19	32	" "	67.10	13.85	" " "
3	13	35	" "	63.54	19.20	" " "
3	300	All		82.48		

Table 10 (Cont'd.)

Class Means and Standard Deviations of EIB 1-6 Total Scores
of High School (9-10) and College Freshman Students

EIB No.	No. Students	Teacher/ Section	Date/ Subject	Class Mean	S. D.	School/ College
			Spring, 1971			
4	17	261	Gen. Biol.	80.29	11.26	Univ. Lab School
4	9	21	" "	76.78	12.67	Private High School
4	16	28	" "	76.56	8.07	Urb. H.S. aff'd/w Univ.
4	29	232	" "	**75.10**	**14.43**	Urban High School
4	7	24	" "	75.43	10.61	Private High School
4	8	23	" "	75.00	8.49	" " "
4	25	15	" "	**74.96**	13.52	Urban High School
4	28	231	" "	71.61	13.45	Urban High School
4	10	16	" "	71.30	11.92	Urban High School
4	23	17	" "	70.87	11.88	" " "
4	20	26	" "	70.30	9.84	Private High School
4	22	25	" "	65.40	8.56	" " "
4	14	27	" "	65.21	9.70	" " "
4	13	25	" "	63.92	15.38	" " "
4	14	29	" "	55.86	14.07	" " "
4	255	All		71.90		
			Spring, 1971			
5	31	15	Gen. Biol.	116.39	15.70	Urban High School
5	27	12	" "	115.85	12.50	" " "
5	13	277	Cons. Biol.	113.62	10.64	Urb. H.S. aff'd/w Univ.
5	21	51	Gen. Biol.	100.95	15.33	Urban High School
5	20	14	" "	104.85	14.69	" " "
5	15	294	Cons. Biol.	97.47	10.78	Urb. H.S. aff'd/w Univ.
5	17	287	Res. Biol.	94.12	14.39	" " " " "
5	20	295	Cons. Biol.	88.15	12.95	" " " " "
5	19	291	" "	86.37	22.85	" " " " "
5	22	298	" "	85.64	16.58	" " " " "
5	17	283	Res. Biol.	84.29	18.72	" " " " "
5	19	34	Gen. Science	83.63	19.18	Urban High School
5	13	32	" "	71.31	12.34	" " "
5	99	All	Gen. Biol.	109.51		
5	123	All	Gen. &Res. Biol.	91.54		
5	32	All	Gen. Science	77.47		
			Spring, 1971			
6	29	15	Gen. Biology	87.97	12.32	Urban High School
6	20	12	" "	86.10	16.88	" " "
6	29	17	" "	83.90	11.66	" " "
6	25	16	" "	82.28	11.17	" " "
6	21	166	" "	82.19	17.69	" " "
6	19	165	" "	79.21	13.28	" " "
6	22	14	" "	78.68	12.93	" " "
6	19	164	" "	78.21	13.41	" " "
6	21	161	" "	75.19	23.41	" " "
6	15	41	" "	73.67	15.54	" " "
6	23	57	" "	69.70	16.07	" " "
6		All		79.38		